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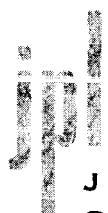
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# The Mariner 2 Infrared Radiometer Experiment

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## The Mariner 2 Infrared Radiometer Experiment

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**Abstract.** Measurements of the 8.4- and 10.4- $\mu$  radiation temperature of small regions of Venus were made using an infrared radiometer on Mariner 2. The radiation temperatures agree with broad-band (8- to 13- $\mu$ ) earth-based measurements, the light- and dark-side temperatures are equal, and there is definite limb darkening. The data are consistent with equal radiation temperatures at 8.4 and 10.4  $\mu$ , which is interpreted as indicating that the emission is from a cloud structure. No breaks in the clouds were observed. A description of the radiometer instrumentation and operation is given.

OUT FOR

**Introduction.** The radiation of wavelength near 10  $\mu$  emitted from Venus was measured before the 1962 conjunction by *Coblentz and Lampland* [1925], *Pettit and Nicholson* [1955], and *Sinton and Strong* [1960]. These observations were made throughout the entire 8- to 13- $\mu$  atmospheric window, although Sinton and Strong also made spectral scans of the unresolved disk. The best spatial resolution was obtained by Sinton and Strong who were able to resolve approximately 1/100 of the area of the planetary disk. The average radiation temperatures obtained were near 235°K, in agreement with the effective temperature expected from the albedo and the observed 3.75- $\mu$  radiation temperatures [Sinton, 1963] but lower than the 600°K radiation temperatures reported at centimeter wavelengths [Mayer, 1959].

When the Mariner spacecraft to Venus was proposed in November 1961, it seemed feasible to make a detailed infrared photometric mapping of the planet. Because of the close approach of Mariner to Venus, it was thought possible to resolve approximately 1/500 of the planetary area and yet, near the peak of the thermal emission,

to make a two-channel spectral selection. Specifically, by comparing the emission at an absorption band of CO<sub>2</sub> and at a spectral region which was presumably clear of gaseous absorption, it was hoped that it would be possible to detect and identify breaks in the cloud structure of Venus through which thermal radiation from the lower atmosphere or surface would be observed. Furthermore, it was intended to make absolute energy measurements unimpeded by attenuation in the earth's atmosphere.

The 10.4- $\mu$  rotation-vibration band ( $\nu_3 - \nu_1$ ) of CO<sub>2</sub> was selected as the appropriate absorption band. For typical models of the Venus atmosphere [cf. Kaplan, 1962], the absorption by the CO<sub>2</sub> above the visible cloud layer would be negligible in this spectral band, while radiation from the surface would be completely absorbed by the CO<sub>2</sub> below the clouds. A second spectral channel was centered at 8.4  $\mu$  since in this region the gaseous absorption is expected to be negligible to depths well below the visible cloud level.

The infrared experiment discussed in this paper was adjunct to, and indeed parasitic to, an experiment designed to map the microwave emission at 13.5 and 19 mm. Preliminary results of both these Mariner 2 radiometer experiments have been published by Chase et al. [1963] and Barath et al. [1963].

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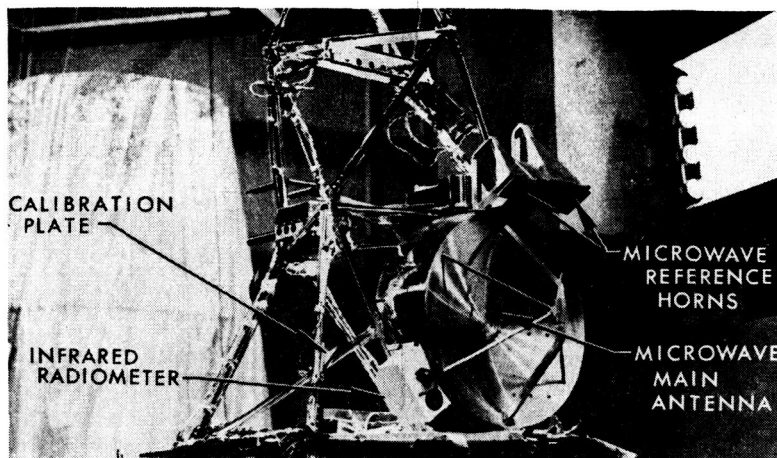


Fig. 1. Infrared radiometer mounted on the microwave radiometer on the Mariner spacecraft. Scanning of both radiometers is accomplished by rotation about the vertical axis.

The spacecraft first encountered Venus at 1854 UT on December 14, 1962. During the four nights of December 14, 15, 16, and 17, detailed thermal mappings of Venus were made at wavelengths between 8 and  $14\ \mu$  by *Murray et al.* [1963a, b] using the 200-inch Hale telescope, and a radiation temperature from the whole disk was obtained by Sinton using the Lowell 42-inch telescope (Sinton, private communication).

**Instrumentation.** The Mariner 2 microwave and infrared radiometers are shown in Figure 1. The total mass of the infrared radiometer, which was housed in a sealed magnesium casting, was

1.3 kg. It required 2.4 watts of power and occupied a volume of  $13 \times 14 \times 10$  cm.

Optically, the infrared radiometer consisted of two similar lens systems whose axes were separated by  $45^\circ$ ; see Figure 2. One system, establishing the chopping reference, viewed dark space and the other, bore-sighted along the same axis as the microwave radiometer, viewed the planet. The energy through the two systems was combined into a single chopped beam by means of a mirrored chopper wheel operating at 20 cps. This beam was in turn split by a dichroic filter into two perpendicular beams which were incident on two thermistor bolometer detectors.

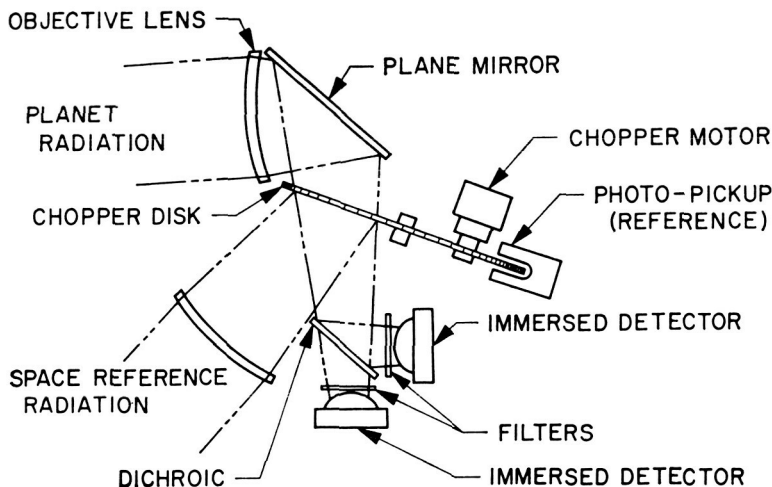


Fig. 2. Schematic layout of Mariner 2 infrared radiometer optics.

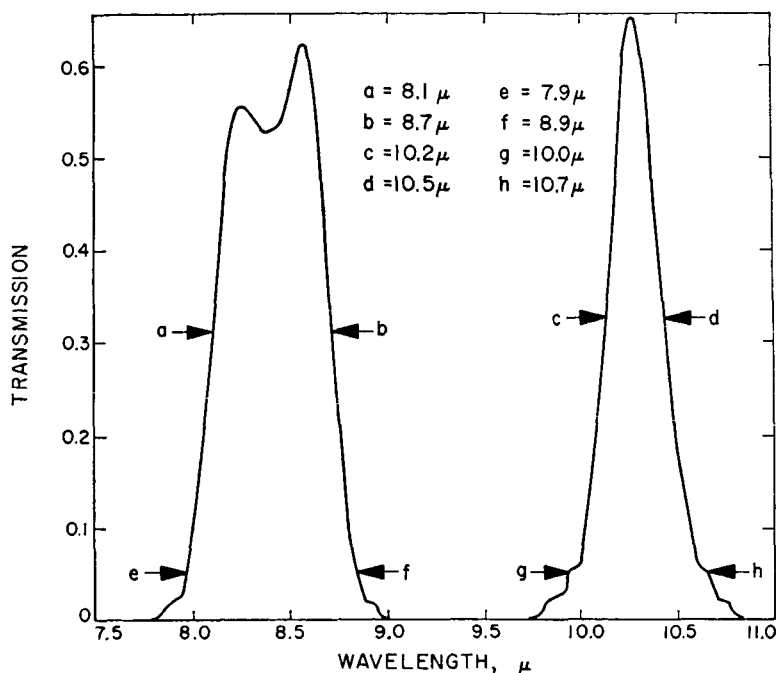


Fig. 3. Spectral response of the two channels of the infrared radiometer

Interference filters placed in front of each detector defined the wavelength region of each channel as shown in Figure 3.

The field of view for each wavelength channel was approximately  $1.2^\circ$  by  $1.2^\circ$ ; see Figure 4. Measurements performed before launch showed that the  $8.4\text{-}\mu$  and  $10.4\text{-}\mu$  channels were offset by approximately  $0.3^\circ$ . An additional effective offset was caused by the scanning motion which moved both fields of view  $0.2^\circ$  during the 2 seconds between the sampling of the  $8.4\text{-}\mu$  channel and of the  $10.4\text{-}\mu$  channel. The two offsets combined in such a way that the two spectral channels viewed areas which overlapped by about 60 per cent. (The sense of the offset can be obtained from the data given in Table 1.) Both beams were within  $0.5^\circ$  of the direction of the main lobe of the microwave radiometer.

The detectors were uncooled thermistor bolometers,  $0.15 \times 0.15$  mm in area, immersed in hemispherical germanium lenses. The germanium objective lenses had a diameter of 3.2 cm, a focal length of 7.8 cm, and were coated with antireflective ZnS optimized for  $9.5\text{-}\mu$  radiation.

Each detector was connected to a transistor-

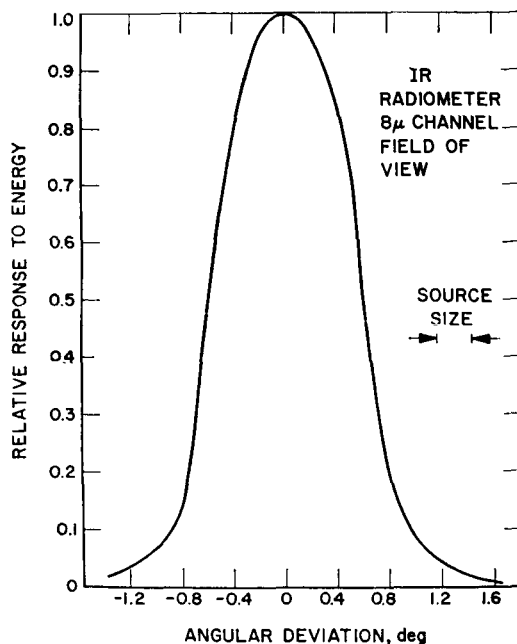


Fig. 4. Field of view of infrared radiometer flown on Mariner 2. The  $10\text{-}\mu$  channel had essentially the same field of view but was offset by  $0.3^\circ$ .

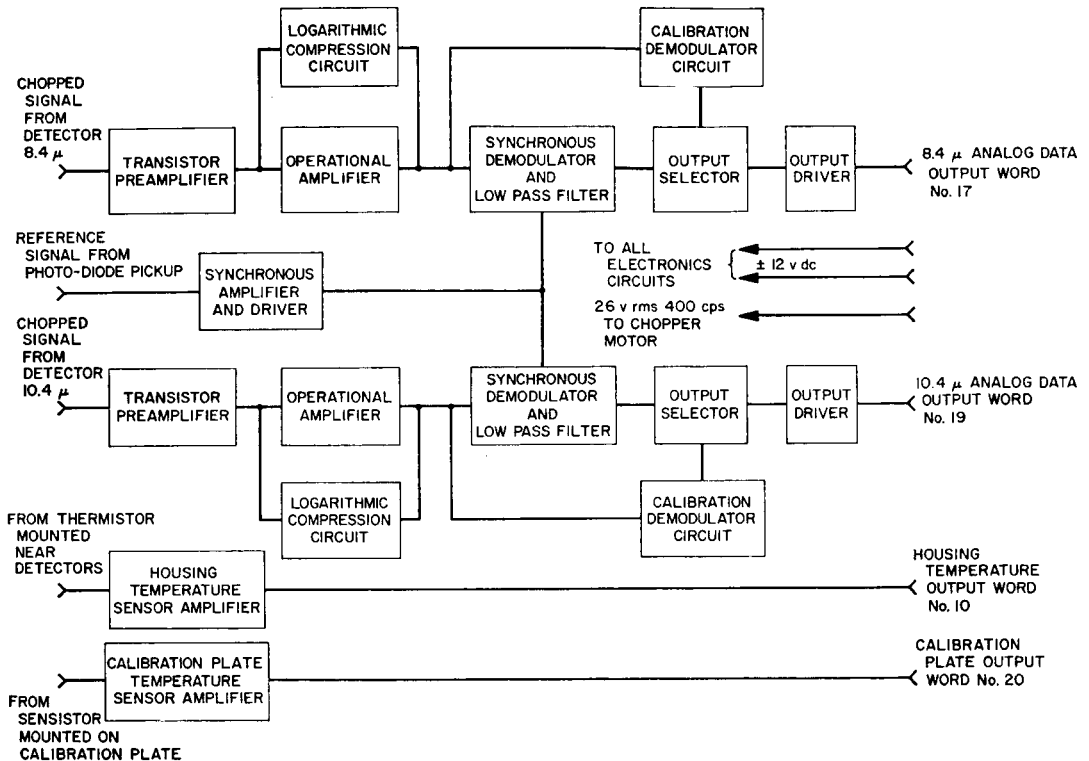


Fig. 5. Circuit block diagram for infrared radiometer. The outputs are sampled by the spacecraft science data handling system, which samples 20 words sequentially in one 20.2-sec subframe.

ized preamplifier, a logarithmic amplifier, a synchronous demodulator, and a low-pass filter. An input dynamic range of approximately 200:1 was compressed into a voltage range of 1 to 6 volts, which in turn was digitized to 213 levels by the spacecraft data handling system. Each detector was sampled once every 20 seconds; the  $10.4\text{-}\mu$  channel was sampled 2 seconds after the  $8.4\text{-}\mu$  channel. The 10 to 90 per cent rise time of the dc output voltage for a step radiation input was approximately 3 seconds. The operation of the infrared radiometer circuit, summarized in Figure 5, has been described by Chase and Schwarz [1962].

The radiometer was designed to measure radiation temperatures between 200 and approximately  $500^\circ\text{K}$ . At  $8.4\text{ }\mu$  this corresponds to flux densities between  $1.0 \times 10^{-4}$  and  $1.8 \times 10^{-2}$  watt/cm<sup>2</sup>. The uncertainty in the measured temperatures caused by noise in the detector and in the electronic system was less than 2 deg. The logarithmic compression and digitization of the

data, however, made the final relative uncertainty vary from about 2 deg for source temperatures near  $200^\circ\text{K}$  to about 10 deg for source temperatures near  $500^\circ\text{K}$ .

Laboratory calibration of the radiometers was performed in a vacuum chamber using the apparatus shown schematically in Figure 6. The blackbodies were copper cylinders coated with Sicon black paint and were placed so as to completely fill the fields of view of the radiometer. The reference blackbody was maintained at  $83^\circ\text{K}$  by pumping liquid nitrogen through coils brazed on the outer surface. The temperature of the 'planetary' blackbody could be controlled between 83 and  $523^\circ\text{K}$ .

The temperature gradients in the planetary blackbody were monitored by 6 thermocouples imbedded in the wall and bottom of the cylinder; even at extreme temperatures, differences were less than 2 deg when data were taken. The effective emissivity of the blackbodies was estimated theoretically to exceed 0.98 using the

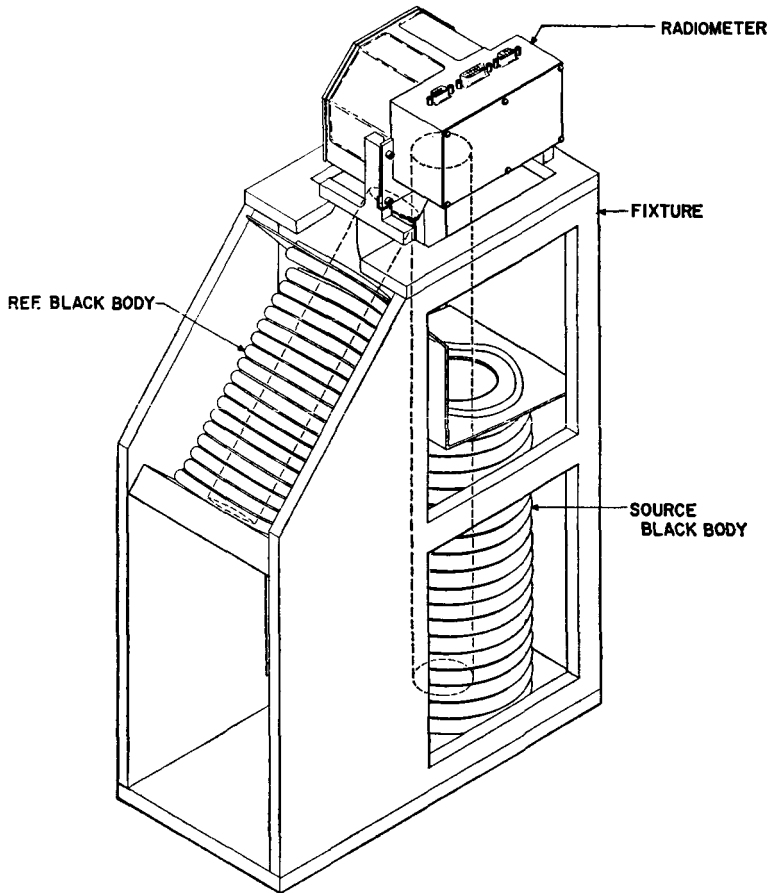


Fig. 6. Apparatus used to calibrate the infrared radiometer.

methods reviewed by *Williams* [1961]. Since the responsivity of the radiometer was sensitive to its housing temperature, the temperature of the radiometer was maintained to within 1 deg of a selected temperature (between 293 and 322°K) by means of a close fitting copper shroud. (The housing temperature was monitored on the spacecraft, and at the time of planetary encounter it had reached 324°K.) The laboratory calibration curves for the unit flown on Mariner 2 are shown in Figure 7. This unit had the poorest characteristics of the three flight units which were built, but it was flown on Mariner 2 because of scheduling conflicts and the loss of Mariner 1.

A one-point in-flight check of the calibration was provided by a plate mounted on the spacecraft in such a way that it was observed by the radiometer at one limit of each complete scan

cycle (see Figure 1). The temperature of the plate was independently measured to an accuracy of about 3 deg using a temperature sensitive resistor. Although this check is crude in establishing the absolute calibrations, it is important to recognize that it afforded the opportunity of observing the same temperature with both spectral channels, and thus served to give a good relative calibration.

Schedule constraints made it necessary that the calibration plate be mounted in the field of view of the reference lens instead of the planetary lens. Since the signal was synchronously demodulated, this reversal of the roles of the two lenses would have caused an unacceptable negative output signal. Therefore, additional circuitry was added which bypassed the synchronous demodulator for potentially negative outputs and provided a positive output regard-

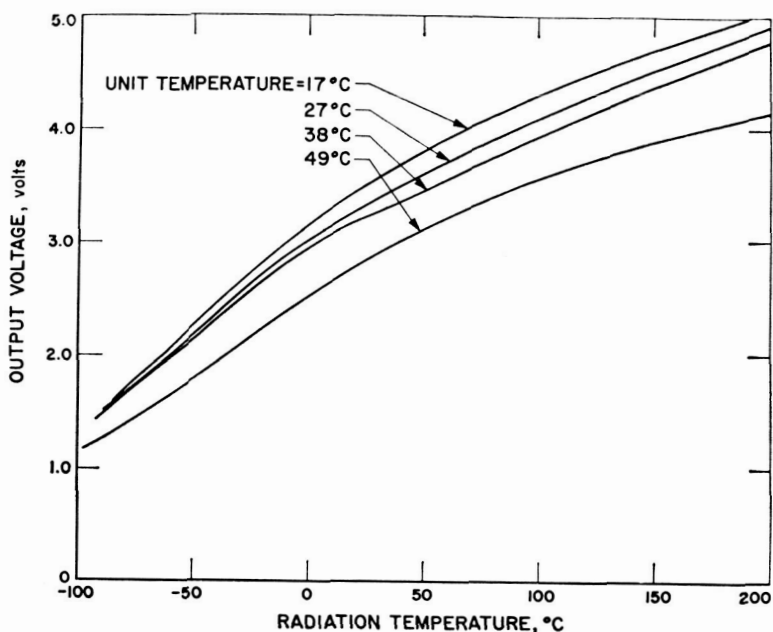


Fig. 7. Laboratory calibration curves of the  $10.4\text{-}\mu$  channel of the radiometer flown on Mariner 2.

less of the sense of the input energy (see Figure 5). As a result, an additional set of laboratory calibrations was required in order to relate the calibrations of the 'normal' operations to the in-flight calibration measurements.

The short time schedule of the Mariner program precluded making long-term stability tests on the actual flight unit. However, a spare unit was calibrated at two times separated by three months. During this period, the sensitivity of

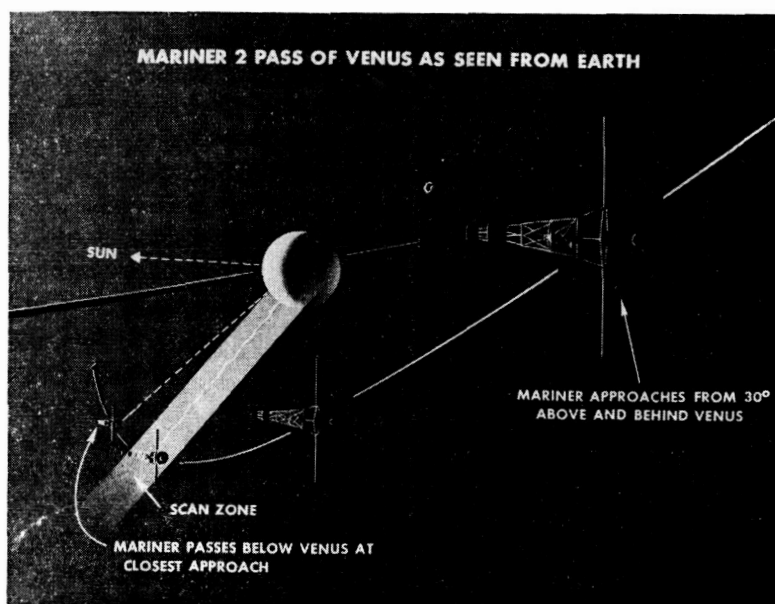


Fig. 8. Over-all features of the encounter of Mariner 2 with Venus. At closest approach the probe was 41,100 km from the center of Venus.

the radiometer decreased less than 20 per cent, the exact shift depending on the temperature of the radiometer. It was possible, however, to reconstruct the correct calibration curve to within 5 deg by using readings from the calibration plate.

Scanning of the radiometers was accomplished by rotating the microwave radiometer about the spacecraft-sun axis, which is shown as vertical in Figure 1. A scan rate of 1 deg/sec was intended to be used to search for the planet in a scan going 60° above and 60° below the earth-spacecraft-sun plane. After the planet was acquired, a logic circuit controlled by the microwave radiometer was intended to scan the radiometers across the disk at 0.1 deg/sec and to reverse scanning at the limbs so that limb to limb scanning was affected.

*Flight performance.* The in-flight sequence of operations of Mariner 2 before encounter with Venus included a 4-min calibration of the microwave radiometer approximately once every six days. Although all of the voltages required to operate the infrared radiometer were not applied during these calibrations, measurements of the temperature of the radiometer housing and of the calibration plate were obtained.

On October 8, 1962, after approximately forty days of apparently normal operation, the analog signals from instruments not having low-impedance outputs showed deviations from their expected values which in some cases were as large as 4 per cent. In particular, voltage shifts appeared in the temperature readings which were correlated with the level of the output of the microwave radiometer. The exact cause of these

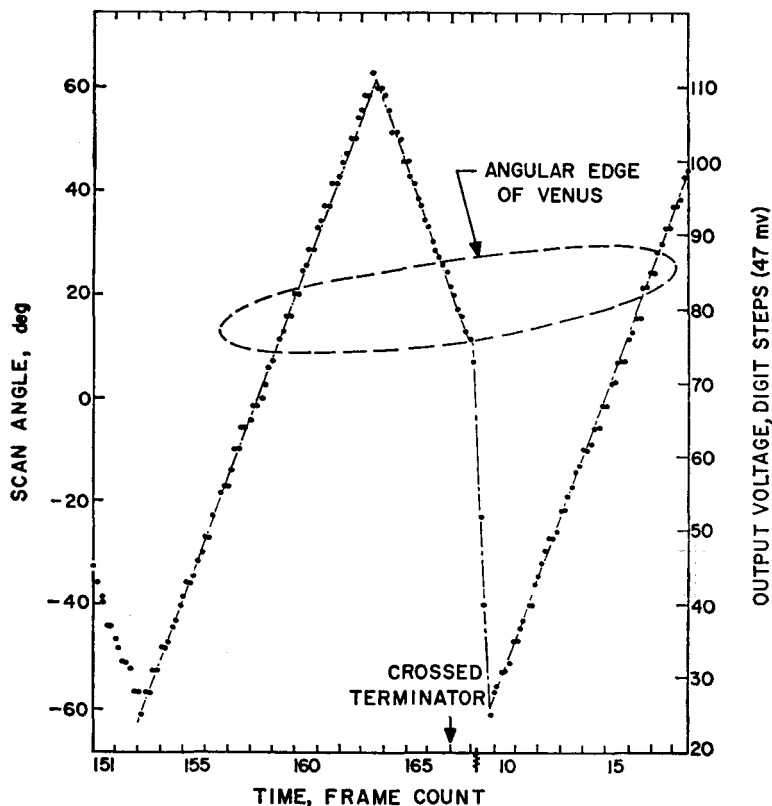


Fig. 9. Radiometer scan angle during those passes when Venus was observed. The points represent the digital outputs obtained from Mariner 2. The scan angle is measured relative to the spacecraft in a plane which is normal to the spacecraft-sun line; it is measured from the earth-spacecraft-sun plane. Six subframes, each lasting 20.2 sec and containing one output reading from each scientific instrument, were obtained in one frame count. Frame count 156 started at 1853 UT on December 14, 1962. The frame count register was accidentally reset when the fast scan was initiated.



anomalies—the understanding of which is important in determining the absolute temperature calibrations—has not been determined, although tests performed at the Jet Propulsion Laboratory on spare units indicate that several high-resistance leakage paths must have been established between components in the data handling system.

On December 14, approximately  $6\frac{1}{2}$  hours before the closest approach of Mariner 2 to Venus, full power was applied to both radiometers and the scanning was started. Because of a malfunction which caused a change in the gain of the microwave radiometer, the scan was in the slow mode, i.e. at the rate of 0.1 deg/sec, instead of the 1-deg/sec fast mode which had been planned. Approximately  $3\frac{1}{2}$  hours before normal encounter there were six passes during which the reference lens viewed Venus. These observations served as a crude check of the orientation of the spacecraft and of the scan

angles, although they gave no scientific or calibration data.

The over-all features of the pass during planetary encounter are shown schematically in Figure 8. Figure 9 shows the digital outputs and the scan angle measured with respect to the spacecraft as a function of time during those scans when Venus was viewed through the planetary lens. The discontinuity which occurred after frame count 168 was caused by the scan going into the fast mode.

It is seen from the superimposed outline of Venus in Figure 9 that only three scans were obtained. The first scan crossed at approximately  $50^\circ$  in longitude in the dark side, the second crossed at the terminator, and the third crossed at about  $60^\circ$  in the light side. The distance from the probe to the center of Venus was approximately 46,000 km during the first scan, 44,000 km during the second scan, and 42,000 km during the third scan.

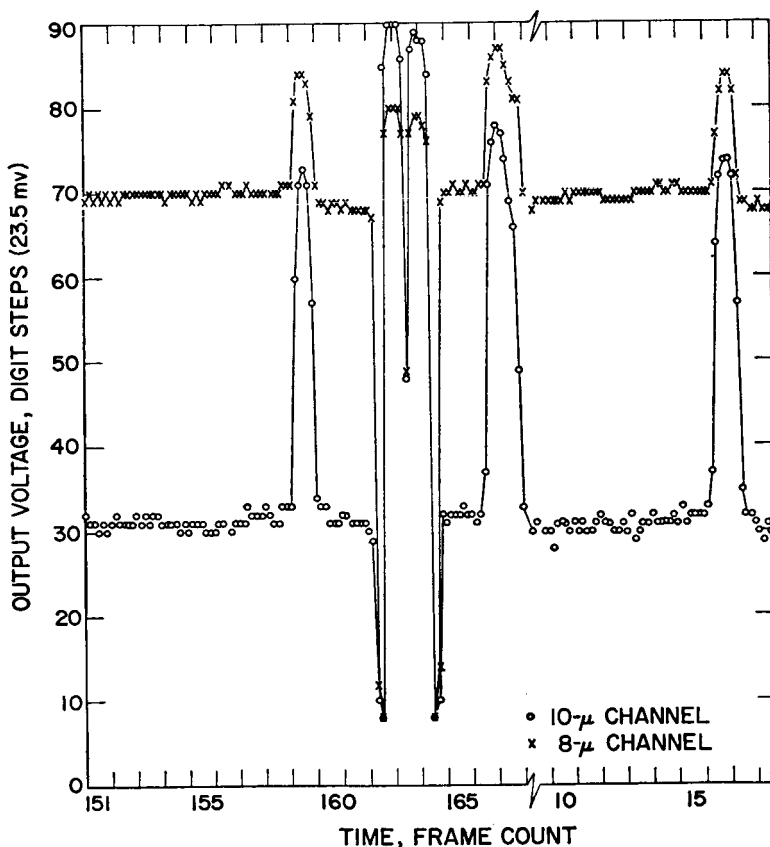


Fig. 10. Unreduced data from infrared radiometer at planetary encounter.

Although about 25 scans were potentially possible, the scan did not reverse at the limbs as planned because of the gain change in the microwave radiometer. Thus 5 per cent of the total surface of Venus was seen instead of 25 per cent. Since the actual miss distance was almost twice the anticipated miss distance, the spatial resolution was degraded to  $1/250$  of the planetary area.

Figures 10 and 11 show the data obtained from the infrared and microwave radiometers during planetary encounter; Venus was clearly observed during frame counts 159, 167, and 17. The pair of peaks around frame count 163 was caused by the reference lens viewing the calibration plate, and was one of ten such calibration pairs that were obtained. The sharp dips which accompany the peaks were caused by the shifting from the planetary to reference modes as the radiometer scanned onto, off, onto in reverse, and then off the calibrator plate.

*Data reduction and results.* The data shown in Figure 10 were reduced to radiation temperatures by using flight calibration curves which

were obtained from the laboratory calibration curves in the following manner. The output voltage corresponding to each radiation temperature was decreased by a constant amount, picked so that at the assumed encounter temperature of the calibration plate, the laboratory and flight calibration curves coincided. Reducing the laboratory output voltages by a constant amount corresponds to assuming that either the optical transmission or the detector sensitivity had decreased, or that the amplifier gains had been reduced by a constant factor. The reduction procedure clearly fails at very low temperatures when the output voltages approach the background level. This failure probably contributes strongly to the apparent anomalies which appear at the limbs of the first and second scans.

It is, of course, possible that the decrease in sensitivity was due to more complex causes than those outlined above. The gain of the amplifiers could have become voltage dependent, the transmission of the reference lens could have changed in a way different from the planetary lens, or

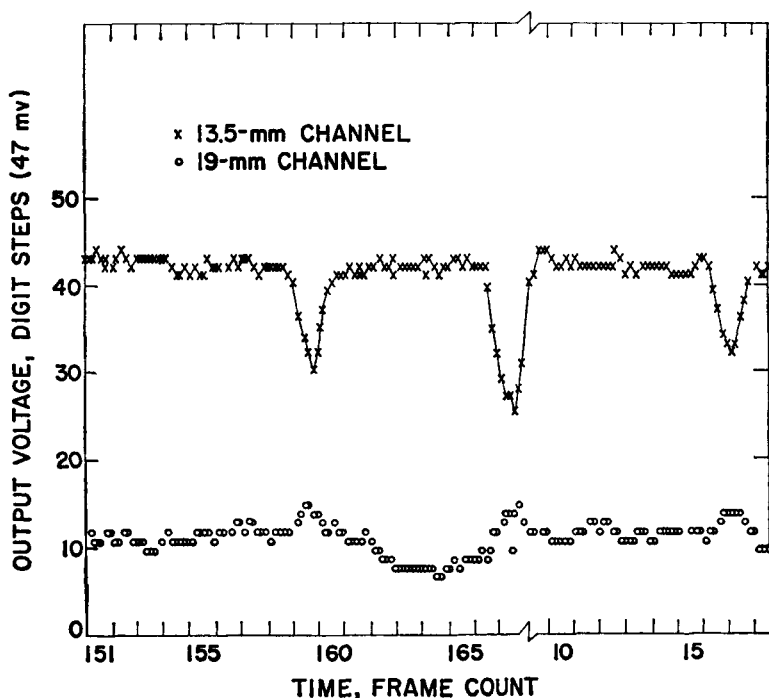


Fig. 11. Unreduced data from the microwave radiometer at planetary encounter. The 19-mm data were taken 9 sec before the  $8.4\text{-}\mu$  data; the 13.5-mm data were taken 1 sec after  $8.4\text{-}\mu$  data. The microwave data extend beyond the infrared data because of the 40-sec time constant of the former radiometer.

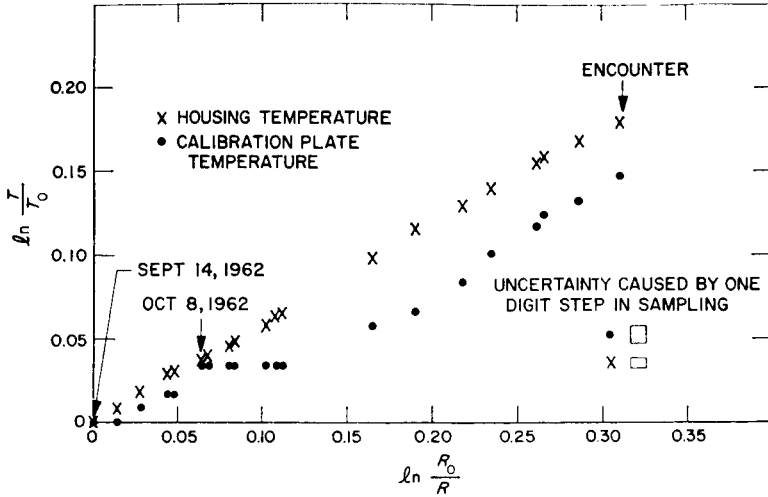


Fig. 12. Temperature of the infrared radiometer housing and calibration plate as a function of the spacecraft-sun distance.  $R_0$  and  $T_0$  are the spacecraft-sun distance and either the housing or calibration plate temperature measured on September 14, 1962.

optical components could have shifted. Since it is impossible to make a correction for these unknown effects, and since the data are reasonably self-consistent, no other method of reduction was extensively pursued and no attempt was made to include these possibilities in the stated uncertainties.

The accuracy of the radiation temperatures depends directly on the accuracy of the measurement of the temperature of the calibration plate. The in-flight cruise temperature data, however, indicated an uncertainty in this measurement connected with the anomalies in the analog outputs which occurred starting October 8. Figure 12 shows temperatures of the calibration plate and of the radiometer housing as a function of the inverse of the spacecraft-sun distance; all values are normalized to the values obtained from the first in-flight measurements. It is seen that starting October 8, when other data anomalies occurred, the calibration plate temperature no longer followed the same power law as the radiometer housing temperature. The coincidence of this happening on October 8 makes the calibration plate temperatures suspect. Therefore, radiation temperatures were computed using two sets of calibration curves based on two assumed values of the calibration plate temperatures. In one case the calibration plate temperature was assumed to be that which corresponded to the voltages actually obtained. In the other case the calibration plate tempera-

ture was derived by assuming that both the plate and radiometer housing temperatures had the same dependence on the spacecraft-sun distance.

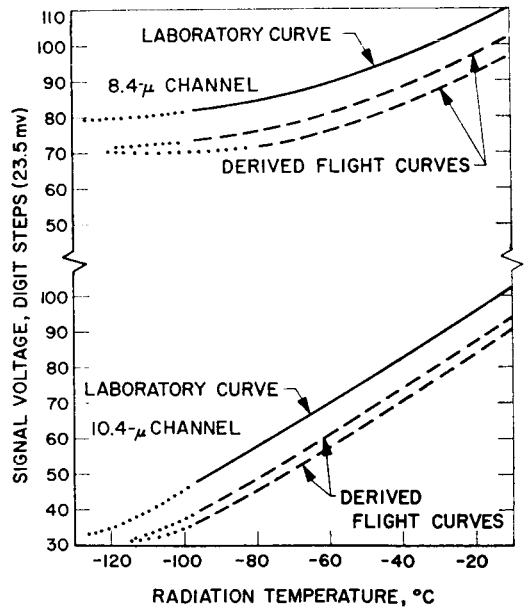


Fig. 13. Laboratory and flight calibration curves for the Mariner 2 infrared radiometer. The upper of the derived curves is obtained by assuming the calibration plate voltage was read out correctly; the lower of the derived curves is obtained by extrapolating the calibration plate temperature (see text).

TABLE 1

Time UT§	Frame Count	8 $\mu$			10 $\mu$			8 $\mu  $			10 $\mu  $			8 $\mu\ $			10 $\mu\ $		
		Lat, Deg*	Long, Deg†	Secant Zenith Angle	Lat, Deg*	Long, Deg†	Secant Zenith Angle	Energy, w/cm <sup>2</sup> $\mu$ $\times 10^{-4}$	Temp, °K	Energy, w/cm <sup>2</sup> $\mu$ $\times 10^{-4}$	Temp, °K	Energy, w/cm <sup>2</sup> $\mu$ $\times 10^{-4}$	Temp, °K	Energy, w/cm <sup>2</sup> $\mu$ $\times 10^{-4}$	Temp, °K	Energy, w/cm <sup>2</sup> $\mu$ $\times 10^{-4}$	Temp, °K		
<i>First Scan</i>																			
18 59 43	159-2	-31.0	296.0	2.16†	-29.7	288.0	2.99†	3.1	215	4.2	210	4.9	228	5.0	216				
19 00 03	159-3	-18.6	306.2	1.64	-17.9	301.9	1.82	4.2	224	7.2	228	6.3	236	8.1	233				
19 00 24	159-4	-06.4	311.1	1.52	-05.6	307.3	1.67	4.2	224	7.8	231	6.3	236	8.8	236				
19 00 44	159-5	+06.8	312.4	1.66	+07.7	308.5	1.84	3.8	221	7.2	228	6.0	234	8.1	233				
19 01 04	159-6	+22.8	308.9	2.38†	+24.5	303.2	3.03†	2.4	208	3.7	206	4.1	223	4.5	212				
<i>Second Scan</i>																			
19 14 50	166-5	+29.3	356.1	1.72	+25.3	353.8	1.56	3.7	220	7.2	228	6.0	234	8.1	233				
19 15 11	166-6	+10.5	357.5	1.20	+07.6	355.4	1.16	5.1	229	8.8	236	7.4	241	10.3	242				
19 15 31	167-1	-04.1	358.5	1.04	-06.6	356.4	1.03	5.6	232	9.6	239	7.8	243	10.9	245				
19 15 50	167-2	-17.3	359.4	1.00	-19.7	357.2	1.00	5.6	232	9.4	238	7.8	243	10.5	243				
19 16 11	167-3	-30.3	0.5	1.03	-32.8	357.9	1.04	4.7	227	8.2	233	6.8	238	9.3	238				
19 16 31	167-4	-44.3	1.8	1.15	-47.2	358.7	1.19	3.8	221	6.6	225	6.0	234	7.5	230				
19 16 51	167-5	-61.3	4.5	1.51	-65.4	359.7	1.65	3.1	215	5.8	221	4.9	228	6.5	225				
19 17 12	167-6		Center Off			Center Off		3.1	215	2.3	192	4.9	228	2.8	198				
<i>Third Scan</i>																			
19 32 45	16-4	-37.5	92.9	6.00†	-40.6	83.7	3.32	1.8	201	5.2	217	3.3	217	6.0	222				
19 33 05	16-5	-30.5	70.0	2.20	-31.9	65.5	1.90	3.5	218	7.5	230	5.4	231	8.6	235				
19 33 26	16-6	-20.3	61.8	1.82	-21.6	58.1	1.65	4.2	224	8.2	233	6.3	236	9.3	238				
19 33 46	17-1	-09.1	58.5	1.86	-10.4	55.0	1.67	4.2	224	8.2	233	6.3	236	9.3	238				
19 34 06	17-2	+04.2	59.3	2.36	+02.4	55.1	2.01	3.5	218	7.5	230	5.4	231	8.6	235				
19 34 26	17-3		Center Off			Center Off				3.7	206			4.5	212				

\* The equator lies in the earth-Venus-sun plane; positive latitudes are in the northern hemisphere.

† Zero longitude is at the terminator; the subsolar point is at 90° longitude. The subearth point was at 327° longitude during encounter.

‡ Partially off planet.

§ The 10- $\mu$  data were obtained 2 sec after the 8- $\mu$  data.

|| These values were obtained assuming the output voltage of the calibration plate to be correct.

¶ These values were obtained by extrapolating the temperature of the calibration plate.

The two sets of flight calibration curves are shown in Figure 13; the temperatures and energies are given in Table 1. If the upper derived curves of Figure 13 are correct, the sensitivity of the radiometer decreased to 0.6 ( $8.4\text{-}\mu$  channel) and 0.8 ( $10.4\text{-}\mu$  channel) of the sensitivity measured in the laboratory; the lower derived curves correspond to a decrease to 0.4 ( $8.4\text{-}\mu$  channel) and 0.7 ( $10.4\text{-}\mu$  channel) of the laboratory sensitivities.

The determination of the area of Venus which was viewed by the radiometer is complicated by uncertainties in the orientation of the spacecraft, by the previously mentioned anomalies in the data system, by the noise (corresponding to roughly 2 deg) on the read-out of the scan position, and by the fact that only three scans crossing the limbs were made.

If it is assumed that the radiometer scanned from one limit to the other at a constant rate, i.e. that the noise on the radiometer scan position read-out did not reflect nonuniform motion, the three scans can be consistently located on the planet. The values of the Venus-centered coordinates of the center of the fields of view for the best fit of the data are included in Table 1. The uncertainty in the scanning direction relative to the spacecraft is about  $0.5^\circ$ ; the diameter of Venus as viewed from the spacecraft was  $16^\circ$ . The effect of this uncertainty on location relative to Venus can be estimated by looking at the numbers in Table 1. Readings were separated by scan angles of  $2^\circ$ .

*Discussion.* Several remarks can be made about the data presented in Table 1.

(1) The  $8.4\text{-}\mu$  and  $10.4\text{-}\mu$  radiation temperatures are in agreement with radiation temperatures obtained from previous and concurrent broad-band, earth-based measurements. Because of the uncertainty in the calibration plate temperature, the Venus temperatures presented in this paper have an uncertainty in absolute value of the order of  $\pm 10$  deg. This error greatly exceeds the uncertainty due to random system noise as indicated by laboratory tests and the fluctuations in the base line voltages during encounter.

(2) There is definite limb darkening. This feature is evident in Figure 14 which shows the energy as a function of the secant of the local zenith angle at the center of the field of view. Except for three pairs of readings taken during

the second scan, which will be discussed in (5), the data taken completely on the planet are scattered about a straight line. The energies were taken from the last four columns of Table 1 since these data are more internally consistent than those shown in the preceding four columns. The gross features of Figure 14 would not be changed if the other calibration plate temperatures were used. Although the data indicated a crude power law dependence, they can be fit to an exponential law equally well and no detailed conclusions about cloud structure can be made.

(3) There is no systematic difference between the temperatures measured on the dark side and those measured on the light side of Venus. This again is in agreement with earth-based measurements.

(4) The data obtained at  $8.4$  and  $10.4\text{ }\mu$  are consistent with equal radiation temperatures at these two wavelengths. One obvious inference is that the energy comes from an opaque cloud structure rather than from the surface; thus the limb darkening would appear to come from a cloud structure rather than the atmosphere.

It is estimated that a temperature difference of more than 10 deg would have been measured between the  $8.4\text{-}\mu$  and  $10.4\text{-}\mu$  channels if a break in the clouds covering more than 3 per cent of

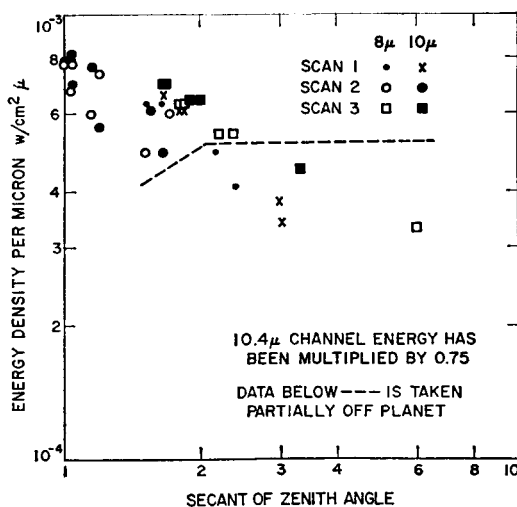


Fig. 14. Energy density per micron wavelength interval received by the infrared radiometer as a function of the zenith angle at the center of the field of view. The energy of the  $10.4\text{-}\mu$  channel has been multiplied by 0.75 to normalize both sets of data.

the field of view had been observed. This estimate is based on the model atmosphere described by Kaplan [1962], in which the temperature in the lower atmosphere varies with pressure as  $p^{0.15}$ , the surface is hotter than  $650^{\circ}\text{K}$ , and the atmosphere is 10 per cent (by volume)  $\text{CO}_2$ . In a break, the  $10.4\text{-}\mu$  energy would have been emitted at an effective temperature of about  $400^{\circ}\text{K}$  and the  $8.4\text{-}\mu$  energy would have been emitted by the surface or lowest levels of the atmosphere at an effective temperature of about  $600^{\circ}\text{K}$ .

(5) As seen in Figure 14, three pairs of readings from the second scan indicate that at both wavelengths the radiation temperatures are considerably lower than expected from symmetrical limb darkening. These data were all taken in the southern hemisphere, completely on the planet, and present a definite contrast to other data obtained at comparable zenith angles. The cold region which these data indicate is also clearly evident from the data of Murray *et al.* [1963a, b]. The complete bilateral symmetry which these authors report was not observed by the Mariner radiometer since the spacecraft was below the ecliptic when observations were made. The small-scale anomaly which was reported by Murray *et al.* occurred near the limb and was not detected unambiguously by the Mariner radiometer. Thus it is impossible, on the basis of the present experiment, to state whether their reported anomaly is a break in the clouds or a cloud temperature variation.

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